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Spatial Analysis of Renewable Energy in Papua New Guinea through Remote Sensing and GIS

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Abstract

Electrification and sustainable energy uses are increasing in Papua New Guinea (PNG) over the last few decades. The bulk of PNG's population (85%) lives in isolated and dispersed villages in the rural areas. Most of these isolated and dispersed areas are still yet to be connected to an electricity supply. Papua New Guinea (PNG) is richly endowed with natural resources, but exploitation has been hampered by rugged terrain, land tenure issues, and the high cost of developing infrastructure. The study is focused on mapping of enriched renewable energy zones of the entire country. Different variables related to renewable, like surface albedo index, earth skin temperature, solar insolation incident, and wind speed are used for this purpose. Three interpolation approaches, like inverse distance weighted averaging, thin-plate smoothing splines, and kriging, are evaluated to interpolate all variables. Rating and weight sum overlay operation is applied to derive potential renewable energy zones in this equatorial country. Results show that potential renewable energy distribution is high in Papua New Guinea on the March and September equinoxes. Yearly average distribution of renewable energy source variables is significantly higher in most areas of Manus, New Ireland, North Solomon, West New Britain, Northern, Central and Milne Bay; a larger portion of East New Britain; the northern part of West and East Sepik, Central, Morobe and eastern part of Madang province. The potential renewable energy distribution data can help to establish sustainable energy production in the country.

Keywords

GIS, Spatial Interpolation, Spatial Analysis, Renewable Energy and Mapping

1. Introduction

Energy, which is originated from natural resources and is constantly replenished, is called as renewable energy

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such as sun radiation, wind speed, geothermal heat, rain, tide and waves [1]. According to the report from Renewable Energy Policy Network for the 21st Century, 19 percent of global energy consumption and 22 percent of electricity generation are contributed from renewable sources in 2012 and 2013, respectively [2]. These sources are traditional biomass (9%), heat energy from non-biomass (4.2%), hydroelectricity (3.8%) and electricity from wind, solar, geothermal, and biomass (2%). Worldwide investments in renewable technologies amounted to more than 214 billion UDS in 2013; countries like China and the United State of America were heavily investing in wind, hydro, solar and bio-fuels. Renewable energy resources exist over wide geographical areas. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits [3]. Based on the report of energy balance by Asia-Pacific Economic Cooperation [4], Papua New Guinea's primary energy supply is projected to increase by 5.1% from 2005 to 2030 annually. Oil and natural gas will comprise mostly in the total primary energy supply. According to the annual report of PNG Power Limited (PPL) [5], hydropower serves Port Moresby, Ramu and Gazelle Systems. Hydropower plants are very old (more than 35 years) and have not been properly maintained by PNG Power Limited. As a result, frequent power cut has been prevalent and growing for many years. Total hydropower generations are reduced by more than 30% of the total annual electricity generation in PNG [6]. The Government of Papua New Guinea recognizes the importance of providing electricity supply for all, and is developing the National Electrification Roll Out Plan (NEROP). Government of Papua New Guinea has requested the support of the World Bank to conduct awareness about wind, small hydro, solar and biomass energy resources and implementation of sufficient sustainable, renewable power generation [7].

In this study four types of renewable energy source were selected such as solar, wind, geothermal and biomass. Airflows can be used to run wind turbines. Modern utility-scale wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5 - 3 MW have become the most common for commercial use; the power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases up to the maximum output for the particular turbine [8]. Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms. In 2013 wind generated almost 3% of the world's total electricity. Solar energy, from the sun, is harnessed using solar heating, photovoltaics, concentrated solar power, solar architecture and artificial photosynthesis [9]. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. Active solar technologies encompass solar thermal energy, using solar collectors for heating, and solar power, converting sunlight into electricity either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). In 2013 solar generated less than 1% of the world's total grid electricity [10]. Geothermal energy is from thermal energy generated and stored in the earth. Thermal energy is the energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive of minerals (80%) [11]. The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface.

This present study is focused on resource mapping and geospatial planning, including spatial data collection, data analysis, GIS mapping of enriched renewable energy zones of Papua New Guinea. The research includes activities aimed at producing thematic outputs for all types of renewable energy resources. Such activities include initial meso-scale studies renewable energy (solar, wind, and geothermal).

2. Study Area and Data Used

Papua New Guinea occupies the eastern half of the rugged tropical island of New Guinea (which it shares with the Indonesian territory of Irian Jaya) as well as numerous smaller islands and atolls in the Pacific. The Geographical Extension of Papua New Guinea is −0˚ to 12˚ south and 141˚ east to 160˚ east. The smaller island groups of Papua New Guinea include the Bismarck Archipelago, New Britain, New Ireland and the North Solomons. Some of these islands are volcanic, with dramatic mountain ranges, and all are relatively undeveloped. Nearly 85 percent of the main island is carpeted with tropical rain forest, containing vegetation that is a combination of Asian and Australian species. Papua New Guinea's climate is tropical, as one would expect in a country located just south of the Equator. December to March is the wet season, although occasional rain falls year-round. While Port Moresby, the capital, and other towns on the coast are quite hot in the summer months, temperatures are considerable cooler in the highlands. Papua New Guinea is a country endowed with vast hydro resources and considerable biomass and solar resources [12]. The social, economic and political circumstances in PNG in past and recent times, however, have meant that these resources have been largely un-utilized. Current study is focused to the major land and islands bounded by 1.5˚ to 12˚ south and 141.5˚ east to 158˚ east (**Figure 1**).

Different types of datasets are used for distribution map preparation of various renewable energy sources within the area. National Aerodonetics and Space Agency (NASA), through its' Science Mission Directorate, has long supported satellite systems and research providing data important to the study of climate and climate processes. These data include long-term estimates of meteorological quantities. These satellite and modeled based products have been shown to be accurate enough to provide reliable solar and meteorological resource data over regions where surface measurements are sparse or nonexistent, and offer two unique features-the data is global and, in general, contiguous in time. Surface meteorology and Solar Energy (SSE) is supported through the Prediction of Worldwide Energy Resource (POWER) project under the NASA Applied Sciences Program within the Earth Science Division of the Science Mission Directorate. They have developed a database of monthly gridded (1˚ × 1˚) climate observations globally using various techniques. Surface albedo index, earth skin temperature, Monthly Averaged Clear Sky Insolation Incident On A Horizontal Surface, and wind speed variable have been taken for this present study. All other details of the variables, data spans along with the sources are given in **Table 1**.

3. Methodology

3.1. Spatial Interpolation

Interpolation techniques predict values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values for any geographic point data: elevation, rainfall, chemical concentrations, noise levels, and so on [13]. Unknown values are predicted with a mathematical formula that uses the values of nearby known points. Interpolation methods can also be portrayed as "global" or "local" techniques. Global techniques (e.g. inverse distance weighted averaging, IDWA) fit a model through the prediction of variable over all points in the study area. Typically, global techniques do not accommodate local features well and are most

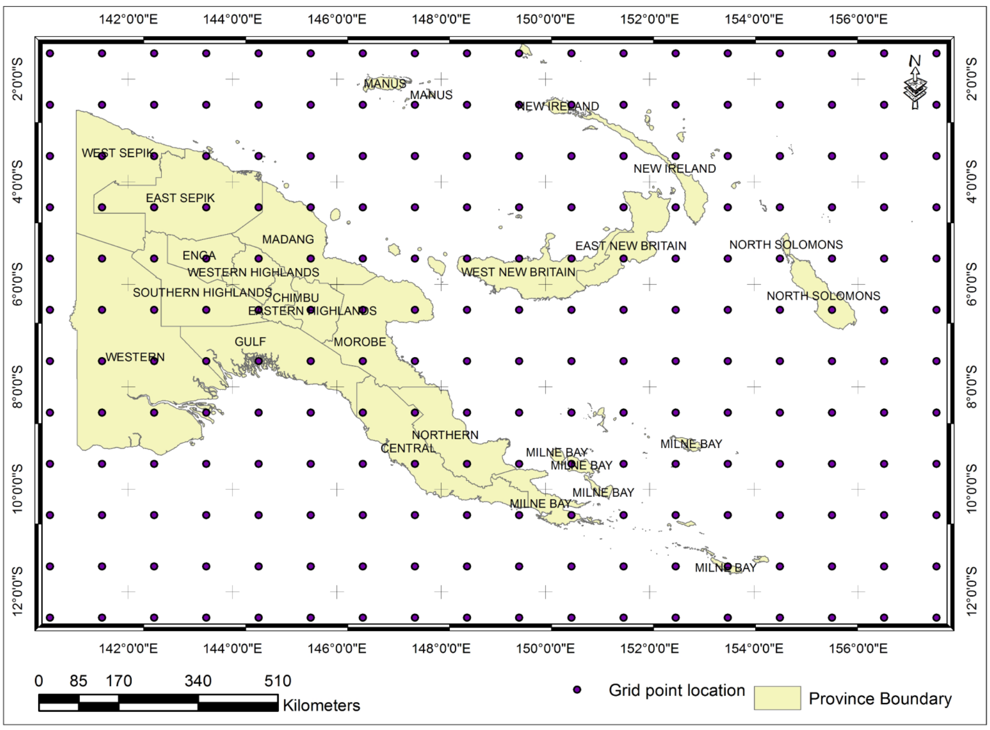

Figure 1. Location map of the study area.

Table 1. Variables for preparation of various renewable energy map.

Variables	Scale	Year/range	Source
Surface albedo index Earth skin temperature (degree C) Clear sky insolation incident (kWh/m^2/day) Wind speed (m/sec)	1 degree × 1 degree, point data	1983-2006	NASA Langley Research Centre, Atmospheric Science Data Centre, Surface meteorological and Solar Energy (SSE) web portal https://eosweb.larc.nasa.gov

often used for modeling long-range variations. Local techniques, such as splining, estimate values for an unsampled point from a specific number of neighboring points. Consequently, local anomalies can be accommodated without affecting the value of interpolation at other points on the surface [14]. Inverse distance weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted [15]. Spline is an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This is a deterministic, locally stochastic interpolation technique that represents two dimensional curves on three dimensional surfaces [16] [17]. There are two types of spline method, they are regularized method and tension method. The regularized method creates a smooth, gradually changing surface with values that can lie outside the sample data range and the tension method controls the stiffness of the surface according to the character of the modeled phenomenon. The inverse distance weighted (IDW) and spline methods are referred to as deterministic interpolation methods because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consists of geostatistical methods, such as kriging, which are based on statistical models that include autocorrelation, that is, the statistical relationships among the measured points. Because of this, not only do geostatistical techniques have the capability of producing a prediction surface, but they can also provide some measure of the certainty or accuracy of the predictions [18].

The ArcGIS v10 software is used for spatial interpolation of the high resolution climate variables. The monthly average and annual measurement of above climate variables are chosen for this purpose. The ArcGIS spatial analyst toolbox was used for spatial interpolation of the climate variables. A point data file was used as inputs for spatial interpolation process based on selected variable. All the three interpolation methods, Inverse distance weighting, thin plate smoothing splines and kriging were used to interpolate clear sky insolation incident, wind speed, surface albedo and earth skin temperature variables.

3.2. Data Classification, Rating and Weight Sum Analysis

Classification of a raster data refers to the value of continuous raster cells are grouped into categories. The weight sum operation under spatial analyst toolbox has the capacity to weight and combine multiple raster data layer input to create an integrated overlay analysis.Eight sum is similar to the weighted overlay operation with multiple raster inputs, multiple factors that can be easily combined incorporating relative importance. This operation uses a common measurement scale and weights of each variable and its subclasses as their importance [19]. Both overlay operations are very much useful for potential suitability analysis and decision support system. Limitation in the Weighted Overlay tool is the weights assigned to the input raster layers must equal to 100 percent. The advantages in weighted sum operation is the user can specify the relative weights as decimals, percentages, or relative weightings. Weighted sum operation simply works based on multiplying the chosen rank values for each input raster data layer by the specific weight. Finally, it creates an output raster layer after summing all resulted values of the individual raster layer together. After interpolation different sets of data (for all the months and annual) were generated to represent different variables spatially. According to the degree of potential energy content to convert them into electric energy, simple statistical weighting/ratings were used for all the variables leading to a decision support approach. We contrived three rating systems, like "3" as a high potential, "2" as a moderate potential, and "1" as a low potential for all variables. Out of four variables clear sky insolation incident is most important to produce electricity using solar plate. Wind speed also very important to produce electricity through wind turbines. A weight of 5 and 3 were designed for clear sky insolation incident and wind speed respectively. All the details about weighting/rating are given in **Table 2**.

4. Result and Discussion

Interpolation processes yields several output files: i) a large residual file which is used to check for data errors; ii) a file that contains an error covariance matrix of fitted surface coefficients; iii) an interpolated thematic map showing the spatial distribution of the parameter. After interpolation, different sets of data (for 4 months and annual) are generated to represent different renewable energy source variables spatially. **Figure 2** represents results of three interpolation techniques based on mmonthly average Earth's skin temperature for the month of December. Spline interpolation method is highly accurate and yield smooth prediction while using uniformly-gridded data (**Figure 2**), but it extrapolate the estimation of values outside the range of tabulated data. Minumum, maximum, mean and standard deviation for each variable were tabulated (Table 3) based on spline interpolation technique. Surface albedo index was recorded high as 0.2070 and low as 0.0392 for the month of June and December respectively. Heights maximum Earth's skin temperature was recorded in the month of December (30.31 ˚C) and lowest minimum in June (20.32 ˚C). Clear sky insolation incident was high in December (8.1310 kWh/m^2/day) and low in June (5.0481 kWh/m^2/day). Month of September experienced maximum wind speed (7.4793 m/s) significantly. Mean and standard deviations of interpolated (spline) variable were calculated for all variables as displayed in **Table 3**.

Table 2. Details of weighting/rating for selected variables.

Surface albedo		Earth skin temperature (degree C)		Clear sky insolation incident (kWh/m^2/day)			Wind speed (m/s)		
Class	Rating	Class	Rating	Class	Rank	weight	Class	Rank	weight
0.04 - 0.1	1	21.05 - 24	1	6.34 - 6.75	1	5	1.54 - 3.00	1	3
0.1 - 0.15	2	24 - 27	2	6.75 - 7.00	2		3.00 - 4.50	2	
0.15 - 0.2	3	27 - 29.75	3	7.00 - 7.37	3		4.50 - 4.95	3	

Table 3. Statistics for the distribution of different variables after spline interpolation.

Months	Statistics	Surface albedo index	Earth skin temperature (˚C)	Clear sky insolation incident (kWh/m^2/day)	Wind speed (m/s)
March	Minimum	0.0403	21.36	6.9098	1.3496
	Maximum	0.1964	30.10	7.8170	4.6600
	Mean	0.0858	28.48	7.5725	3.3343
	Std dev	0.0428	1.87	0.1995	0.7289
June	Minimum	0.4136	20.32	5.0481	1.5943
	Maximum	0.2070	29.79	6.7600	7.3616
	Mean	0.0856	27.72	6.0869	4.0751
	Std dev	0.0446	2.22	0.3987	1.2187
Sept	Minimum	0.0379	20.94	6.4313	1.6610
	Maximum	0.1992	29.45	7.5780	7.4793
	Mean	0.0876	27.50	7.2981	4.2642
	Std dev	0.0426	1.95	0.2409	1.1999
Dec	Minimum	0.0392	21.57	6.7335	1.4141
	Maximum	0.1872	30.31	8.1310	4.5733
	Mean	0.0838	28.70	7.5045	3.2547
	Std dev	0.0407	1.83	0.3138	0.7034
Annual	Minimum	0.0406	21.05	6.3354	1.5396
	Maximum	0.1954	29.75	7.3687	5.9472
	Mean	0.0860	29.10	7.1281	3.7307
	Std dev	0.0424	1.93	0.2217	0.8980

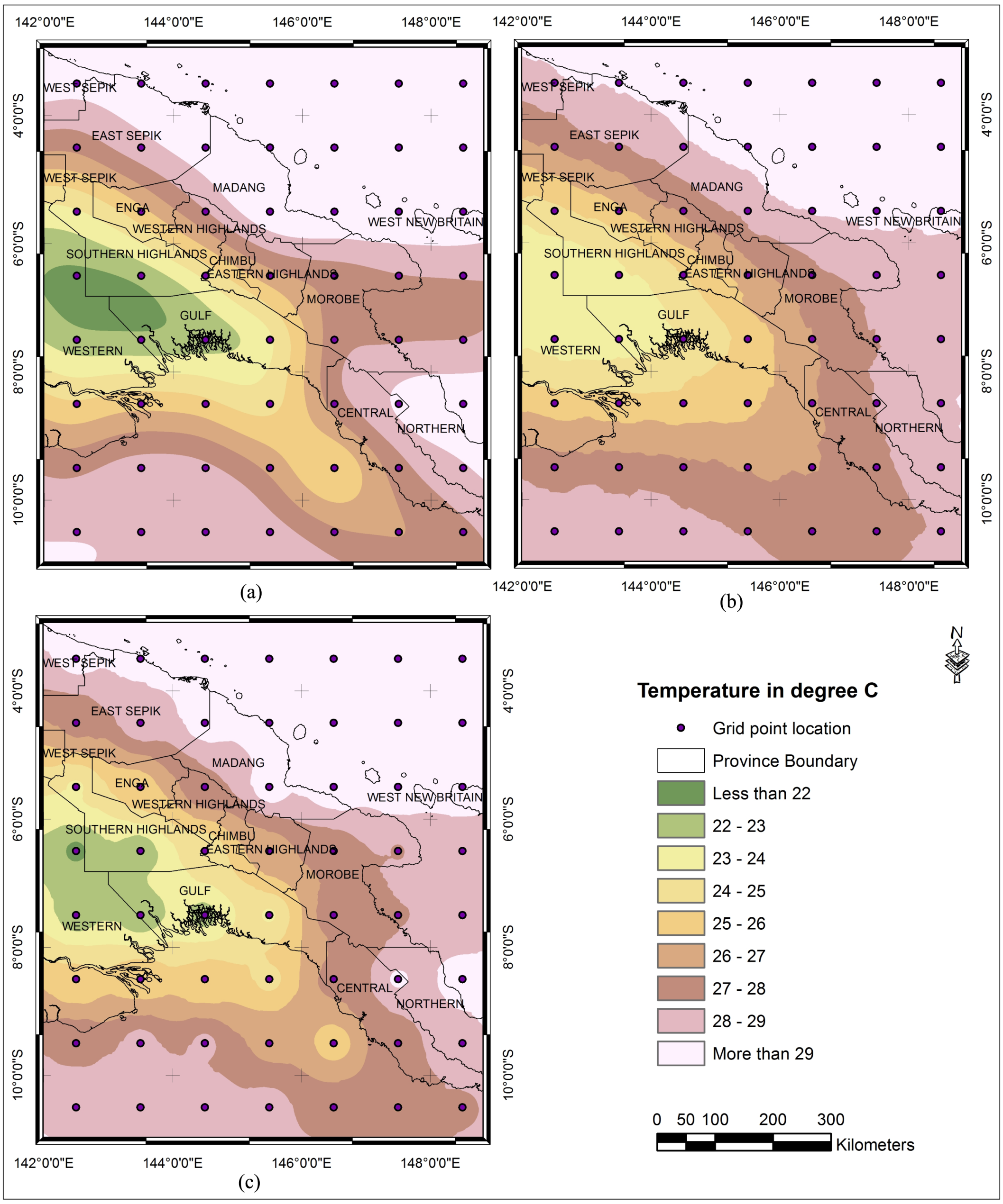

Figure 2. Monthly average Earth's skin temperature for the month of December using interpolation methods (a) splining, (b) kriging, and (c) IDWA.

Result after spline interpolation for annual average clear sky insolation incident, wind speed, surface albedo and earth skin temperature variables were mapped and displayed in Figures 3(a)-(d). Interpolated annual result along the north coast of PNG was significantly lower for annual average surface albedo index (0.0406) and average wind speed (1.5396 m/s) and higher in the middle portion of the country 0.1954 and 5.9472 m/s respectively. Reverse results were cropped out with high average Earth's skin temperature (>29˚C) and high clear sky insolation incident (>7 kWh/m^2/day) along the north coast region.

All four variables were used for weight sum overlay analysis based on their significance rating and weight to find out the potential renewable energy distribution annually and monthly basis. Based on four special days in a year (summer solstice, equinox and winter solstice) four different months (December, March, June and September) were chosen to analysis potential renewable energy distribution. Weight sum overlay model had produced a

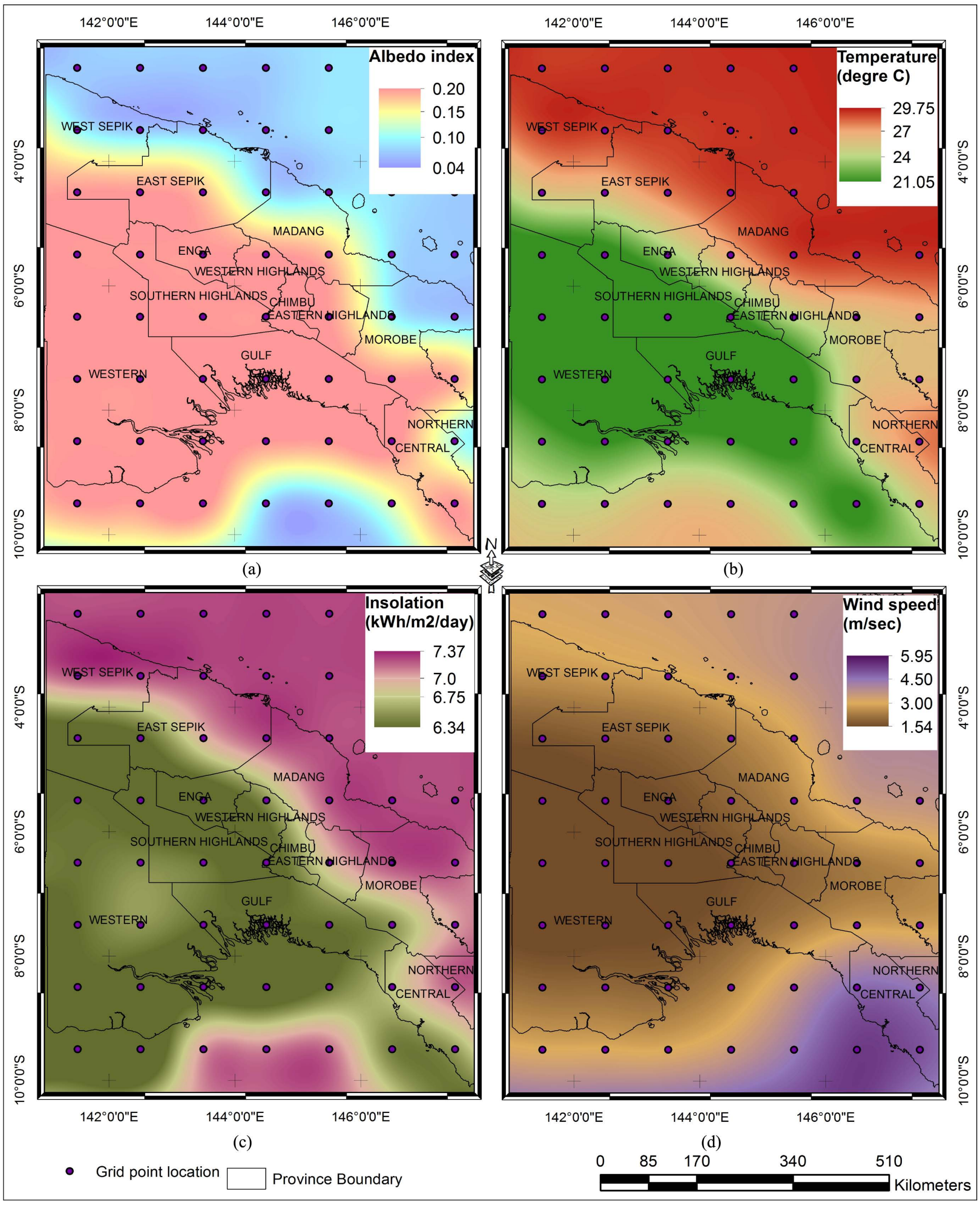

Figure 3. Spline interpolation of Annual average (a) surface albedo, (b) Earth skin temperature, (c) clear sky insolation incident and (d) wind speed.

range of spatially distributed total value ranged from 12 to 30. Higher value refers scale of potentiality of renewable energy. Output value again classified into five (5) groups as: i) very low potential (Less than 13), ii) low potential (14 to 16), iii) medium potential (16 to 20), iv) high potential (20 to 24), and v) very high potential (more than 24). Different thematic map for average potential renewable energy distribution in different months and annual is shown in **Figures 4(a)-(e)**. In the month of March (**Figure 4(a)**) renewable energy distribution is very high in scale in the northern part of West and East Sepik and most areas of Manus, New Ireland, North Solomon, East New Britain, West New Britain, Northern, Central and Milne Bay Provinces of PNG. All other remaining location is characterized by high potential. Month of June (4b) is not significant with high renewable energy distribution because of winter solstice. **Figure 4(c)** and **Figure 4(d)** are representing renewable energy

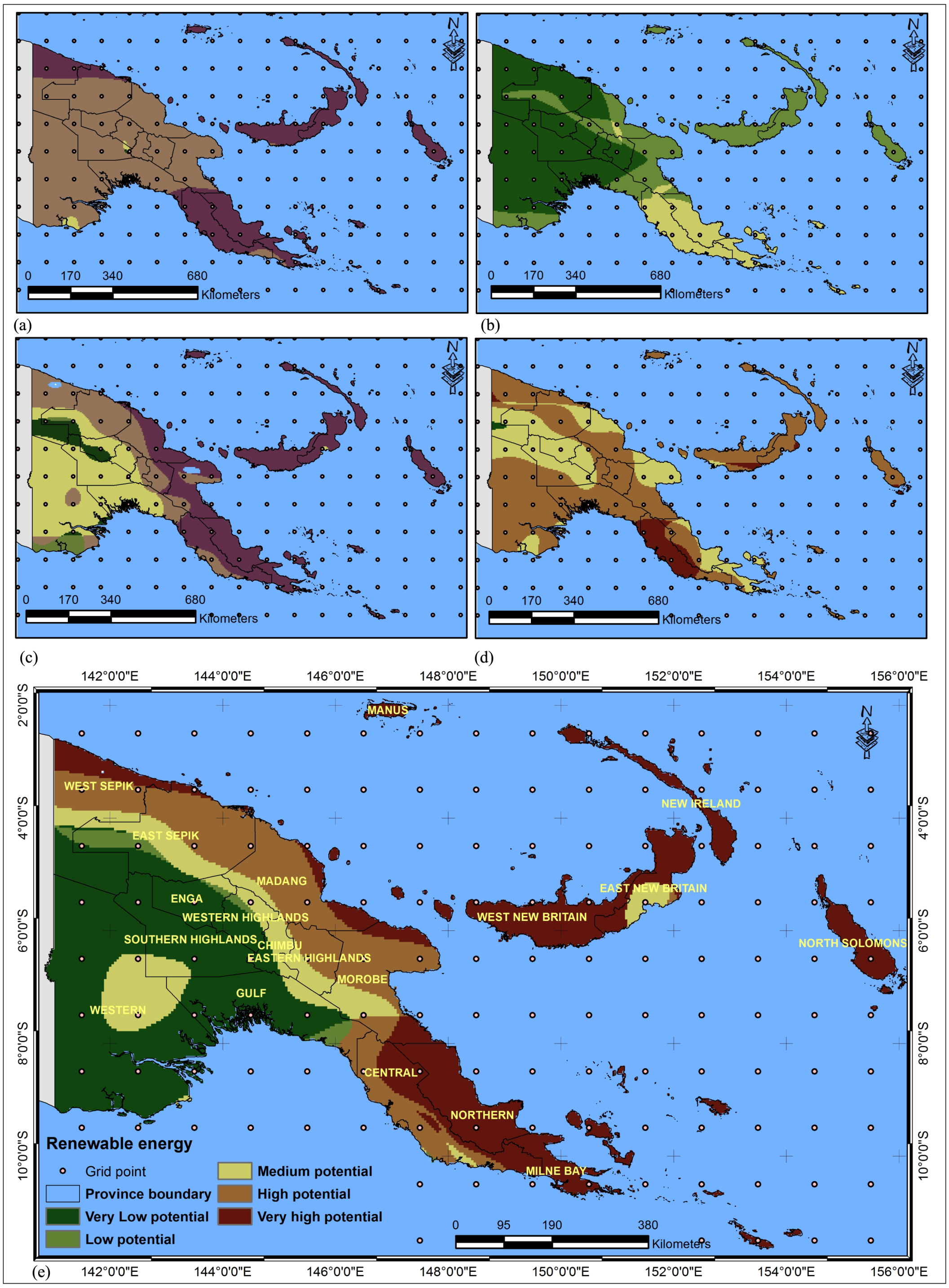

Figure 4. Average potential renewable energy distribution in (a) March; (b) June; (c) September; (d) December and (e) Annually.

distribution of the month September and December respectively. Very high and high potential energy distribution can be found during these months because of equinox and summer solstice. Finally annual renewable energy distribution map is displayed in **Figure 4(e)** to know overall condition of a particular location of PNG. Potential renewable distribution is higher in its intensity diagonally from the south-west to the north-east. Very high potential renewable energy can be found in most areas of Manus, New Ireland, North Solomon, West New

Britain, Northern, Central and Milne Bay; a larger portion of East New Britain; and the northern part of West and East Sepik, Central, Morobe and eastern part of Madang province.

5. Conclusion and Recommendations

Spline interpolation is preferred to kriging and inverse distance weighted because it is faster [13] and easier to use with an input of uniformly-gridded point data. For potential renewable energy distribution modeling, we used surface albedo index, earth's skin temperature, monthly averaged clear sky insolation incident on a horizontal surface, and wind speed. There is also possibility to bring other source of renewable energy into play like geothermal, water, sea wave etc.; then, the model may predict even more accurate results. As the result suggests, two variables (clear sky insolation incident and wind speed) out of four variables are likely to be major sources of renewable energy in PNG. The potential renewable energy distribution map can help to establish sustainable energy production for the country. The incentive to use 100% renewable energy, for electricity, transport, or even total primary energy supply globally, has been motivated by global warming and other ecological as well as economic concerns. Renewable energy use has grown much faster than even advocates anticipated [20]. Energy costs with a wind, solar, water system should be similar to today's energy costs [21], thus helping confront issues related to climate change, energy security, and the escalation of energy costs. Renewable energy is an attractive option because renewable resources available in the Papua New Guinea, taken collectively, can supply significantly greater amounts of electricity than the total current demand. The most significant barriers to the widespread implementation of large-scale renewable energy and low carbon energy strategies are primarily political and not technological. The current social/political problems in the country may have exacerbated existing problems with regards to provision of energy infrastructure to the country's population. According to the Post Carbon Pathways report [22], which reviews many international studies, the key roadblocks are climate change denial, the fossil fuel lobby, political inaction, unsustainable energy consumption, outdated energy infrastructure, and financial constraints.

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